Conservation Innovation Grant (CIG)
Final Project Report

Managed Grazing for Improved Soil Health and Environmental Protection

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Deliverables identified on the grant agreement
- 3-5 evening pasture 'walks' for livestock producers and other stakeholders to see the demonstration sites and learn about the CIG project,
- a one day grazing management workshop targeting livestock producers in year 2 or 3 highlighting results from demonstration studies,
- a one day in-service training in year 3 for VCE agents and NRCS personnel focusing on grazing management and highlighting findings from study,
- two scientific publications in journals or meeting proceedings,
- three popular press articles,
- two Virginia Cooperative Extension publications,
- three presentations at regional or national scientific meetings.

Other deliverables for NRCS include:
- Semi-annual reports,
- Supplemental narratives to explain and support payment requests,
- Performance items specific to the project that indicate progress,
- New technology and innovative approach fact sheet,
- Participation in at least one NRCS CIG Showcase or comparable NRCS event during the period of the grant,
- Final report.

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Executive Summary

The overall goal of this proposed project was to demonstrate how grazing management could affect aspects of soil health, forage characteristics, and nutrient loss in pastures. The specific objectives evaluated how mob and rotational stocking methods affected: 1) indices of soil health, 2) soil nutrient distribution across pastures, 3) forage availability, quality and species composition, and 4) soil erosion and runoff. Stocking method demonstrations were established at two farms in Virginia to compare: 1) mob stocking, 2) rotational stocking, and 3) continuous stocking. Measurements from the demonstrations began in spring 2013 and continued until fall 2015. Most indices of soil health did not differ among the three stocking methods. Soil nutrient distribution also did not change appreciably from 2012 to 2015. More forage mass accumulated under mob stocking compared with the other stocking methods, but forage nutritive value was usually higher under continuous grazing. Forage nutritional value appeared to progressively worsen each year under mob stocking. Soil erosion and nutrient loss from rainfall simulations did not differ among stocking methods. In summary, our study showed that although mob stocked pastures could accumulate more forage, nutritional value may decline over time. The type of grazing management had minimal effects on soil health but this may be related to the short duration of the study. Stocking method effects on soil health may take more than three years to become apparent. Overall in this short-term evaluation, mob type stocking appeared to offer few clear advantages to forage production and soil health over rotational stocking.

Introduction

This project was conducted at two demonstration farms in Blacksburg and Raphine, Va. from 2013 to 2015. Dr. Ben Tracy in the Department of Crop and Soil Environmental Sciences at Virginia Tech led the project with primary assistance from Drs. Cully Hession (Biological Systems Engineering), and Mark McCann (Animal and Poultry Science) also from Virginia Tech. Dr. Hession was responsible for the soil runoff and erosion studies while Dr. McCann helped coordinate the grazing projects. The overall **goal** of this project was to demonstrate how grazing management can affect soil health, pasture productivity, plant diversity and nutrient loss in pastures. Our specific objective evaluated how **mob and rotational stocking** methods affected: 1) soil health as measured by total organic matter content, particulate organic matter content, soil microbial activity, and physical properties (soil compaction), 2) soil nutrient distribution across pastures, 3) forage availability, forage quality, ground cover and overall pasture plant diversity with particular focus on clover, and 4) soil erosion and runoff. Grazing demonstrations included three stocking methods that were compared - mob, rotational and continuous stocking. Mob pastures were grazed in May and September at a stocking density of ~130,000lbs live wt./ac. moving cattle every 12-24 hr. Rotational paddocks were grazed at 15,000 lbs/ac. moving cattle every 3-4 days. Cattle on continuous and rotation systems stayed on pastures from early May to November. From 2013 to 2015, forage was sampled monthly for biomass and nutritive value and plant species composition was evaluated 3 times each year. Soil nutrients were measured within grids established in 2012 and re-sampled in 2015. Other soils were collected at the end of the study (2015) and major soil C pools analyzed. Soil compaction

was measured in spring of 2013 and 2015. Soil erosion was evaluated at one site using rainfall simulation. The project was funded by a Virginia NRCS Conservation Innovation Grant and from Virginia Tech John Lee Pratt Animal Nutrition Program.

Background

This project focused on managed grazing, and its effect on forages and soil health. Broadly defined, managed grazing involves intensive decision-making to control livestock stocking rates and forage removal from pasture to produced desired outcomes. Typical grazing management in much of Virginia usually involves confinement of livestock within defined partitions of pastureland with minimal management of stocking rate or control of forage removal. This is often called continuous grazing.

This study focused on two types of managed grazing whose benefits to profitability and animal output per unit land area have been amply demonstrated- mob and rotational stocking. Mob stocking is method of stocking livestock at a high density for a short time to remove forage rapidly. It is often termed 'mob grazing' or ultra-high stock density grazing in the popular press. Mob stocking was first promoted by Allan Savory in the 1980s as part of a more holistic approach to rangeland management. With mob stocking, a large number of animals are restricted to a small area, either eating or trampling all the plants before being moved to new grass sometimes just after a few hours. Grazing usually starts later in the season (e.g., late May/June in Virginia) when pastures have more growth. The mob stocking is then followed by a long recovery period – usually approaching 90 days. Pastures under mob stocking are grazed just once or twice per season. Rotational stocking uses recurring periods of grazing and rest among three or more paddocks in a grazing management unit throughout the time when grazing is allowed. It is similar in principle to mob stocking except stocking density is lower and pasture recovery periods are much shorter – e.g., 15-30 days.

Overall, research and observational studies from pastures strongly point to the benefits of mob and rotational stocking methods. They include:

1. Healthy soil, with high organic matter, water-holding capacity, and an abundance of microorganisms, earthworms and dung beetles.
2. An even distribution of recycled soil nutrients and organic matter across pastures from the intensive management of animal stocking density.
3. Desirable plant diversity with few weeds and consistent seasonal ground cover that will help build organic matter and reduce soil erosion.

Although studies have compared rotational stocking with continuous stocking, little information exists about mob stocking relative to other stocking methods.

Review of Methods

Demonstration Sites

This project was conducted at two demonstration farms in Blacksburg and Raphine, Va from 2013 to 2015. Grazing demonstrations in Blacksburg were conducted at the Prices Fork Research Center (Montgomery County, VA). The site consisted of 7.5 ha (18 acre) of pastureland **(Figure 1)**. Soils were well-drained Groseclose and Poplimento loam soils (Fine, mixed, semiactive, mesic Typic Hapludults and Fine, mixed, semiactive, mesic Ultic Hapludults, respectively), with slopes ranging from flat to moderately steep, 2% to 25% slopes (Soil Survey Staff, 2010, 2014). For 20 years before 2012, the pasture was cut once or twice a year for cool-season grass hay and rarely fertilized. Tall fescue, orchardgrass, Kentucky bluegrass, and sweet vernal grass (*Anthoxanthum odoratum* L.) were the predominant vegetative cover in April 2012.

Figure 1. Stocking method layout at Blacksburg site.

Commercial fertilizer (10-10-10) was applied in 2006 and in April 2013 commercial fertilizer was applied according to soil test recommendations. Ladino clover (*Trifolium repens* L. 'Will') and medium-sized red clover (*Trifolium pratense* L. 'Cinnamon Plus') were broadcast in February 2013 at 1 and 2.5 kg ha^{-1} (3 and 6 lbs acre^{-1}), respectively, across all paddocks. Research in Raphine (Augusta County, VA)
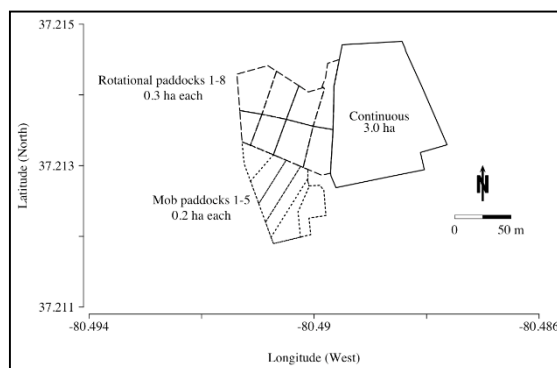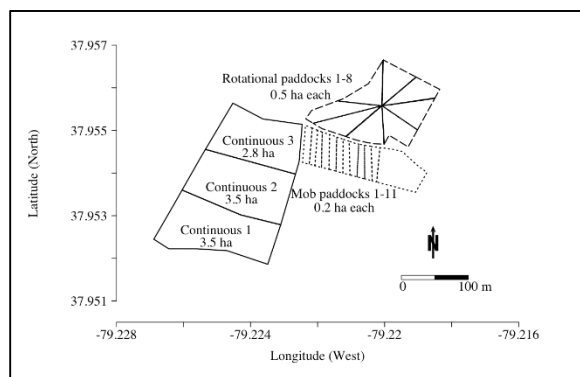

Figure 2. Stocking method layout at Raphine site.

was conducted on a private farm leased to Virginia Tech. The site consisted of 16 ha (40 acre) of pastureland **(Figure 2).** Soils were well-drained Frederick and Christian gravelly silt loams (Fine, mixed, semiactive, mesic Typic Paleudults, and Fine, mixed, semiactive, mesic Typic Hapludalts, respectively), with slopes ranging from flat to moderately steep, 2% to 25% slopes. Sweet vernal grass, tall fescue, white clover, and bluegrass were the predominant vegetative cover in April 2012. The pasture was rested in 2012 and had been managed for cool-season grass hay before then. Previous fertilization is unknown but commercial fertilizer and lime was applied according to soil test recommendations in April 2013. Ladino clover and red clover were broadcast in February 2013 at 1 and 2.5 kg ha^{-1} (3 and 6 lbs acre^{-1}), respectively, across all paddocks.

Beef cows (ave. 610kg/1300 lbs) and steers (ave. 310kg/ 680 lbs) were stocked, respectively, at the Blacksburg and Raphine locations at similar stocking rates (~1 Animal Unit (AU)/2 acre) where ; 1 AU = 454 kg/1000lbs live BW). Water and mineral were offered *ad libitum*. At the Raphine and Blacksburg sites, mob stocking consisted of two stocking periods each year of 12- to 16-h duration, stocking densities were 138,000-155,000 kg live BW ha^{-1} (125,000 -140,000 lbs LW/acre. on 0.1- 0.2-ha (0.25-0.50 acre) paddocks, and rest periods were

90- to 120-d during the growing season. Rotational stocking consisted of 6 to 7 stocking periods of 3- to 4-d duration on 0.3 to 0.7 ha (0.75 to 1.75 ac) paddocks with fixed 28-d rest periods. Continuous stocking consisted of one uninterrupted stocking period that spanned the duration of the growing season (110 to 196 d).

Forage Mass

Standing forage biomass at Blacksburg and Raphine was harvested at monthly intervals each year by clipping all vegetation within 0.25-m^2 square quadrats to the soil surface with sheep clippers or hand shears. Samples were taken at fixed intervals of 30-50 m apart; seven to 26 quadrats were harvested in each paddock each month. **Figure 3** shows an examples of the sampling locations at the Blacksburg site. Sampling points were identified with a hand-held GPS (Juno 3B, Trimble Navigation Ltd., Huber Heights, Ohio). Harvested forage biomass was dried in a forced-draft oven at 55˚C for 48 h and then weighed. Forage accumulation and disappearance also was measured using moveable exclosures and measuring forage mass inside and outside exclosures each month during the growing season.
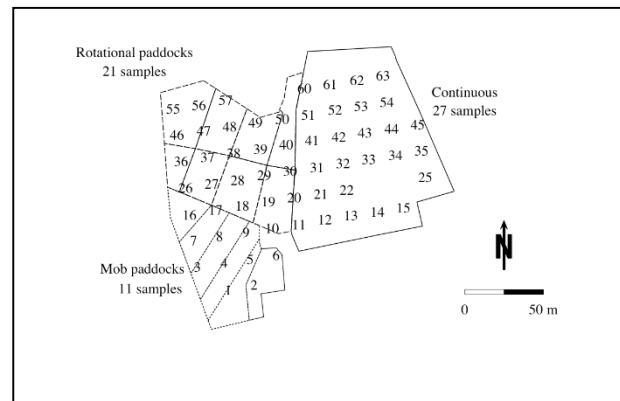

Figure 3. Grid sampling layout at Blacksburg site.

Plant Species Composition

Percent cover of forage, dead material, and bare soil was measured in 0.5-m^2 rectangular quadrats in spring, summer, and fall at the Blacksburg and Raphine locations. Estimates of percent cover of individual species in each quadrat were recorded in the field and each estimate was later scaled so that the sum of all components was 100. Percent covers of clover, forage, and weed species were calculated by summing several components: clover was the sum of red and white clovers; forage was the sum of bluegrass, orchardgrass, and tall fescue; weed was the sum of all other live vegetation. Bare ground and dead material were also quantified.

Forage Nutritive Value

The oven-dried samples of standing forage biomass harvested from all locations were milled with Thomas-Wiley mills (2-mm screen; Philadelphia, PA) and cyclone mills (1 mm screen; Cyclotec, Hilleroed, Denmark) and then scanned with Near Infrared Reflectance Spectroscopy (NIRS; FOSS 6500, Hilleroed, Denmark). Forage nutritive value and moisture content were predicted with a fresh forage equation. Accuracy of the fresh forage equation was assessed with the Global H (Mahalanobis distance) and Neighborhood H statistics. Crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) were predicted as percent by mass of the total sample and scaled to a dry matter basis.

Soil Nutrients and Soil Health Indices

Soil samples were collected in 2012 and 2015 from grid geo-referenced grids at each farm (e.g., Figure 3). Soils were collected to a 10 cm (4 in.) depth at each location and analyzed for standard nutrients at the Virginia Tech Soil Testing Lab. Soil compaction or penetration resistance (SPR) also was measured in early 2013 and 2015 at the same grid points using a FieldScout SC-900 Soil Compaction Meter (Spectrum Technologies, Inc., Plainfield, Illinois). Measurements were recorded every 2.5 cm (1 in.) from the soil surface to 30 cm (18in.) depth. Site maps to evaluate the spatial distribution of nutrients were created using Kriging in ArcGIS 10.0.

The soil samples to access soil carbon pools and health indices were collected in late May 2015 at the time of the highest forage production. For each stocking method, samples were collected along 2 transects, at distances from livestock water areas. Sample location were 3, 5, 10, 20, 40, 60, and 80m from water sources. Transects were in two directions from the water in the continuous pastures and in two paddocks in the rotational and mob pastures, taking into account any differing slopes and aspects. For each sample, three soil subsamples were gathered with a soil auger to a depth of 10 cm within 1 m of the designated distance and mixed in a bucket. Fresh manure piles were avoided. While in the field the samples were kept in a cooler in the shade and upon return stored in a refrigerator or cold room until analyzed. The samples then were sieved through a 4mm mesh screen and homogenized. Approximately 5-10g of soil was packaged in whirlpacks and frozen in -80°C freezer for DNA analysis.

Water holding capacity and gravimetric water content were obtained from remaining soil. For water holding capacity, a small amount of soil is saturated with water and then allowed to drain for 2 hours. The weight at water holding capacity is obtained, and the soil is oven dried at 105°C until the no more water can be evaporated from the soil, usually 24 hours. Gravimetric water content was measured by taking a small amount of soil, weighing it before oven-drying it at 105°C and then after oven-drying it until the weight of the soil remained consistent.

Soil pH was obtained through a 2:1 water extraction in the lab and through a 1:1 water extraction in the Virginia Tech Soil Testing Lab. Soil tests for macro and micro nutrients were completed at the Virginia Tech Soil Testing Lab.

Microbial activity and functioning was estimated through carbon mineralization, substrate-induced respiration, and nitrogen mineralization. Carbon mineralization was measured over 65 days, incubated at 20°C and kept as close to 65% water-holding capacity. The initial measurement was obtained after the soil was measured and moisture adjusted, flushed the next day and read on an Infrared Gas Analyzer (IRGA) the third day. The second measurement was taken 5 days later and after that weekly for a total of 10 measurements.

For substrate-induced respiration, a solution of hydrolyzed yeast was added to 4g dry weight soil, shaken for 1 hour, flushed with CO_2-free air, and incubated for 4 hours at 20°C. CO_2 production is measured on an IRGA.

Nitrogen mineralization was conducted in the lab with an initial measurement and a measurement after a 28-day incubation period, as indicated in the protocol by Knoepp (M

Strickland personal communication, May 27, 2015). Approximately 10-g dry weight of soil was measured into two containers, one for the initial extraction and the other for the 28-day extraction. For the initial extraction, 50mL 2M KCl was added, the Nalgene bottle was shaken, placed overnight in a 4°C refrigerator, and 10mL of extraction was pipetted off the top. The extraction was frozen in a -20°C freezer until analysis. The 28-day incubation at 20°C was moisture adjusted to 65% water holding capacity on a weekly basis, and extracted on day 28, the same procedure as the initial one. The nitrogen mineralization was analyzed on a Lachat autoanalyzer, measuring ammonium and nitrate-nitrite.

Microbial biomass is estimated with simultaneous chloroform extraction and substrate-induced respiration. Substrate-induced respiration (SIR) estimates the active microbial biomass using established protocols. Autolyzed yeast was added to 4g dry weight of soil, vortexed, shaken for 1 hour and then incubated for 5 hours. CO_2 concentrations were measured on an Infrared Gas Analyzer (IRGA).

Simultaneous chloroform extraction estimated the microbial biomass by the amount of microbial carbon and nitrogen extracted through treating the soil with K_2SO_4 and chloroform at the same time. The method involves adding 0.5M K_2SO_4 to 7g dry weight of soil for both non-fumigated and fumigated samples. 1mL EtOH-free chloroform was added to the fumigated samples. The samples were shaken for 4 hours, filtered through Whatman No. 42 paper, and bubbled vigorously with moisture-extracted house air for 60 minutes to remove any remaining chloroform. The extracts were frozen until analysis. Total organic carbon was obtained on a total carbon analyzer and dissolved inorganic nitrogen was analyzed on a Lachat autoanalyzer. For total nitrogen analysis, 5mL of extract was pipetted into 15mL centrifuge tubes, frozen, freeze-dried, encapsulated into 9x10mm tin capsules, and analyzed with a micro-CN Analyzer.

Two fractions of particulate organic matter were tested. Soil was air-dried for a week and 10g of soil was measured into Nalgene bottles, to which 30mL 5% NaHMP solution was added. The mixture was shaken for 18 hours. After which, the soil was physically separated through a 53μm sieve. The mineral fraction was washed through the sieve with approximately 2L of DI water. After a quick blending of the mineral fraction, a 150-mL beaker was filled and 135mL was measured into a graduated cylinder and poured into the Nalgene bottle. The mineral fraction was frozen, freeze-dried and then ground to a powder. The POM fraction was washed out of the sieve into a tin, dried overnight in a 105°C oven, and ball milled. For both fractions, approximately 10mL samples were packaged into 9x5mm tin capsules and analyzed in a micro-CN analyzer.

Soil microbial communities were examined through fungal to bacteria ratios. DNA extraction was done with a MO BIO PowerSoil® DNA Isolation Kit, and the concentration was measured with Qiime Qubit fluorometer. The fungal:bacterial ratio will be obtained with qPCR (quantitative Polymerase Chain Reaction), examining 16S rRNA for bacteria and ITS (Internalized Transcribed Spacer) primer for fungi.

Soil Erosion and Nutrient Loss

Soil erosion and nutrient loss were measured at the Blacksburg site in 2013. Runoff plot sites were chosen in each pasture to achieve a slope of approximately 15% for each. The maximum number of simulated rainfall events that could be performed over a two-day consecutive period was ten. Therefore, ten plots sites were established: three in each stocking system. Final plot locations were geo-referenced using a hand-held global positioning system (GPS) unit. In order to observe seasonal changes in runoff quantity and quality, rainfall simulations were planned to occur monthly during the grazing season and once after the removal of livestock.

Rainfall Simulations

A total of 54 rainfall simulation events were performed in 2012. A rainfall simulation was performed at each plot before grazing began, then approximately monthly after cattle had been introduced, and once after cattle were removed. Runoff plots (2 by 2 m in area) were designated by steel borders driven at least 10 cm into the ground. At the downslope edge of the plots, galvanized runoff collection pans were installed. Collection pans were triangular-shaped pieces of stainless steel sheet metal with outer edges molded to channel flow to an outlet. Each collection pan was fitted with a garden hose bib at the outlet. Plot borders and runoff collection pans were installed prior to each simulated rainfall event. Plot borders and pans were removed between events so as to not interfere with cattle behavior. Runoff plots were pre-wetted the day before each event by uniformly applying water to the surface of each plot using a hose until runoff occurred. Pre-wetting was necessary because of the unusually dry conditions during 2012. Pre-wetting was also used in an attempt to normalize soil moisture among Plots.

Immediately prior to each event, the following plot condition data was collected: visual estimation of ground cover percentage, volumetric soil moisture content (SMC) using a Hydrosense Soil Water Measurement System (Cambell Scientific, Inc., Logan, UT), and soil penetration resistance (SPR) using a FieldScout SC-900 Soil Compaction Meter (Spectrum Technologies, Inc., Plainfield, IL). Prior to initiating rainfall at each plot, five 150 mL non-recording rain gauges were placed inside the plot (one in each corner and one in the center of the plot) to collect applied rainfall. The rainfall simulator was centered over the plot. Water from the onsite well was pumped into two 1,325 L tanks and transported to the runoff plots to be used as the simulated rainfall source water.

After 2.5 min of continuous runoff, a 1 L sample was collected (water quality (WQ) sample). Likewise, WQ samples were collected at 12.5, 22.5, and 32.5 min after runoff was initiated. Runoff that was not collected for detailed chemical analysis was collected through a garden hose connected to the collection pan and into a series of 19.4 L buckets (flow samples). After the final WQ sample was collected, rainfall was halted. Runoff collection continued until the flow was no longer steady at which time the duration of runoff was recorded. Grab samples were collected from the rainfall source water for each day of rainfall simulation and processed for water quality analysis.

Samples were processed in the field on the same day of collection. Flow samples and the empty buckets were weighed. WQ samples were weighed and prepared for water quality analysis by mixing the WQ sample and portioning four 250 mL samples, two unfiltered (raw) and two filtered at 0.45 μm pore diameter. A Geotech Geopump was used with 0.45 μm disposable filters to filter runoff samples. One raw and one filtered sample from each WQ sample and rainfall simulator source samples were frozen and shipped to the United States Department of Agriculture – Agricultural Research Service (USDA-ARS), Pasture Systems and Watershed Management Research Unit in University Park, PA for nutrient analysis.

Findings

Forage Mass and Production

At Blacksburg and Raphine, the amount of forage mass differed among the stocking methods (**Figure 4**). Mob stocked paddocks contained on average 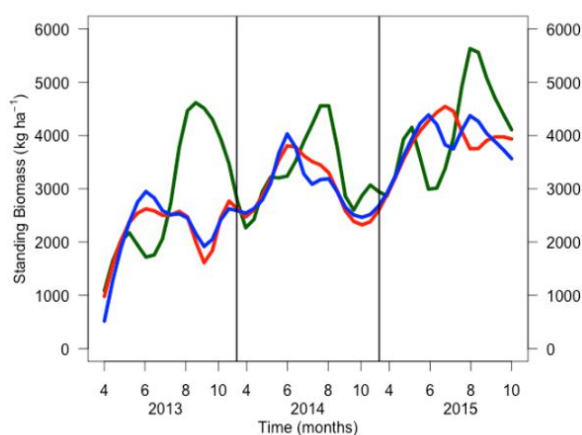600 kg ha^{-1} (540 lbs/ac.) more forage than rotationally or continuously stocked paddocks. Forage mass about 350 kg ha^{-1} (315 lbs/ac.) greater at Blacksburg compared to Raphine. Forage mass in April was less than in subsequent months, however, average forage mass in subsequent months did not differ. Mob stocked pastures tended to accumulate more forage during the late summer compared with the other stocking method (green line in Figure 4). Forage accumulation did not differ among the stocking methods, but disappearance (i.e. use by cattle) was lower under mob stocking. Overall, these findings suggest that mob stocked pastures had more forage mainly because cattle ate less probably because much of the tall grass was trampled and difficult to graze.

Figure 4. Forage mass measured over the three years of the study. Green line = mob, red line= Cont. and Blue line= rotational

Pasture Plant Species Composition

A major interest in the plant species composition measurements was to evaluate how overseeding clovers would establish under the different stocking methods. As shown in **Table 1**, continuous pastures had more white clover than other stocking methods. The result was mainly due to the short grazing that occurred in the pastures, which tends to favor white clover establishment especially if rainfall is adequate. The amount of bare ground was lowest under mob stocking likely due to the high amount tall grass that was trampled during grazing. Bare ground was low in all stocking methods, however. The upright growth habit of red clover likely conferred its tolerance to shading by grasses during mob and rotational stocking and allowed it to

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establish relatively well. White clover also tends to colonize bare ground, which would explain why continuously stocked areas would have greater white clover cover than mob stocked areas.

Table 1. White clover, red clover bare ground percentage averaged over the growing season.

	Cover type		
Stocking method	**White clover**	**Red clover**	**Bare**
	———————% ———————		
Continuous	7.5	4.2	3.3
Mob	2.5	3.6	1.1
Rotational	3.0	3.1	3.3
SE	2.0	1.2	1.2

The percent cover of forage, weed, and dead plant material did not differ statistically among stocking methods: mean cover of forage, weed, and dead material were 48, 14, and 24 percent, respectively. However, the proportion of each component varied widely across time (**Table 2**). Cover of clovers and forage generally increased and cover of weeds decreased from the beginning to the end of the study in all treatments. However, clover cover at Raphine declined to 2% in October 2014 after reaching 9% in July 2013. In 2013, clover cover at Raphine in 2013 was less than at Blacksburg. Overall, Blacksburg also had more weed cover and less dead material than Raphine. Forage cover was generally less in May and July of each year relative to October; cover of clovers and dead material were generally greater in May and July and lesser in October. In summary, the stocking methods did not produce major differences in the composition plant functional groups over the course of this study. Although we did record data on individual plant species during the course of this study, no major changes were noted. Probably, it may take longer than 3 years to see substantial changes in species composition in response to grazing management in humid pasturelands like these.

Table 2. Percent cover of grass, clover, weeds and dead plant material over the 2013 and 2014 growing seasons. Data from 2015 is not shown, but showed a similar trend.

	Time period						
Cover type	**May 2013**	**July 2013**	**Oct. 2013**	**May 2014**	**July 2014**	**Oct. 2014**	*SE*
Grass (%)	43	60	52	41	46	59	3
Clover (%)	3	10	8	12	9	9	2
Weed (%)	19	16	6	14	10	16	3
Dead (%)	25	--	28	27	26	10	4

Forage Nutritive Value

The main effects of stocking method on ADF, CP, and NDF concentrations in herbage were not different until 2014 and 2015. As shown in **Figure 5** for crude protein (CP), continuous pastures generally had higher concentrations especially in 2014 and 2015 (red line on graph). These higher nutritive values were mainly due to the higher amount of white clover in continuous pastures. Forage had slightly higher nutritive values at Blacksburg with values containing about 10 g kg^{-1} more CP, 16 g kg^{-1} less ADF, and 34 g kg^{-1} less NDF than forage at Raphine. Nutritive value of forage varied across time: CP was greatest in May, least in July-September, and intermediate in October (**Figure 5**). Trends for ADF and NDF were similar to CP so are not shown. Nutritive values did not dip below the limiting threshold set for beef cow maintenance (e.g., 90 g kg^{-1} or 9% for crude protein). However, values were getting

Figure 5. Forage crude protein measured over the three years of the study. Green line = mob, red line= Cont. and Blue line= rotational.

close to falling below the threshold for mob stocked pastures in 2015. Our findings suggest forage nutritive values under mob stocking may worsen over time since grasses are allowed to become excessively over-mature each year before grazing.
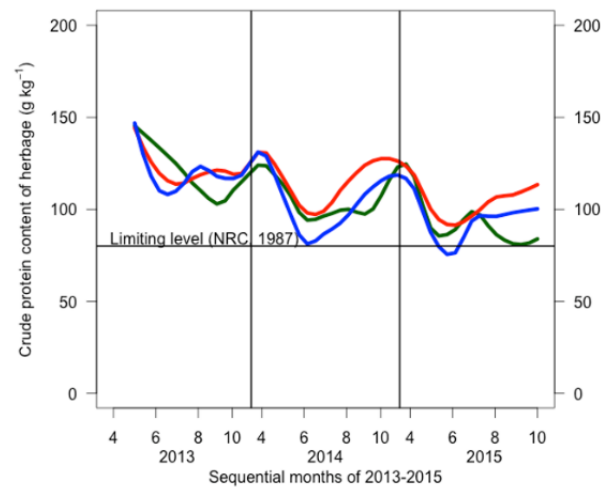
Soil Nutrients

Another objective of the study was to evaluate whether stocking methods would change the spatial distribution of soil nutrients over time. To do this, we took soil samples at the start and end of the study in geo-referenced grids at each site (see Figure 3). Soils were analyzed for pH and major macro and micro nutrients. **Table 3** shows some of the nutrient levels before grazing or fertilization was done (2012) and in 2015. Note the 2012 data was collected before lime and P/K fertilizer was applied thus explaining the large increases in most macro-nutrients. Lime was not applied at Blacksburg site which may explain the decrease in pH. Soil organic matter (OM) did not change at the Raphine site but increased about 10% in Blacksburg. Overall, mob or rotational stocking did not appear to increase soil OM or other nutrients substantially more than continuous stocking over this three year period.

Table 3. Soil pH, selected macronutrients and organic matter (OM) measure at the start of the study in 2012 before grazing and fertilization started (pre) and the final year in 2015 (post).

	Raphine Site (BF)									
	Continuous			Mob			Rotational			
	2012	2015	%diff	2012	2015	%diff	2012	2015	%diff	
pH	5.9	6.4	8%	5.9	6.5	10%	6	6.4	7%	
P	1.8	5.5	206%	2.3	4.6	100%	4	5.7	43%	
K	114	120	5%	62	77	24%	65	76	17%	
Ca	466	603	29%	393	489	24%	586	612	4%	
Mg	72	145	101%	52	123	137%	60	134	123%	
OM	3.5	3.6	3%	3.1	3.1	0%	3.7	3.5	-5%	
	average	59%			49%				31%	
	Blacksburg Site (PFRF)									
	Continuous			Mob			Rotational			
	2012	2015	%diff	2012	2015	%diff	2012	2015	%diff	
pH	6.1	5.6	-8%	6	5.9	-2%	6.1	5.9	-3%	
P	7.7	9.3	21%	5.3	8.4	58%	6.9	9.4	36%	
K	27	64	137%	28	74	164%	28	71	154%	
Ca	439	589	34%	478	587	23%	485	524	8%	
Mg	101	131	30%	113	142	26%	101	133	32%	
OM	2.9	3.4	17%	3.1	3.4	10%	2.9	3.2	10%	
	average	38%			47%				39%	

For brevity, phosphorus maps generated of the Raphine site will be presented as they illustrate the general spatial pattern found between 2012 and 2014**(Figure 6)**. Except for some increase due to P fertilization in 2013, most P concentrations did not change much spatially. We hypothesized that under continuous stocking more soil nutrients were build up around water areas where animals congregate and deposit manure and urine. This did not occur. Nutrient 'hotspots' identified in 2013 resulted from historical hay feed areas. These areas were still visible in 2015 and no new regions of nutrient concentration were noted near water sources established in 2013. Soil nutrients under mob stocking were evenly distributed in 2013 and

UK-Soil P-2012

BF-Soil P, ppm
- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 10
- 10 – 15
- 15 – 18
- 18 – 28
- 28 – 43
- 43 – 55
- 55 – 60

Rotational

Mob

Continuous

Benson Farm
Augusta Co., VA
March 2012

0 70 140   280   420   560
Feet

UK-Soil P-2015

BF-Soil P, ppm
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 10
- 10 - 15
- 15 - 18
- 18 - 28
- 28 - 43
- 43 - 55
- 55 - 60

Rotational

Mob

Continuous

Benson Farm
Augusta Co., VA
March 2015

0 70 140   280   420   560
Feet

2015. Again, three years may not be enough time for soil nutrient changes to be noted with great clarity.

Soil Health Indices

Several indices of soil health were measured in this study that mostly associated with soil carbon and nitrogen pools. These pools have a major impact on soil nutrient availability for growing plants so can influence the productivity of pasturelands. Soil compaction was also evaluated in 2013 and 2015 as a physical index of soil health.

Few consistent differences among stocking methods were noted for the biological soil health indices measured in 2015 (**Table 4**). This was mainly because of strong site differences between the farms that dominated the variance in soil health indices.

Figure 7 gives an example of three soil C pools and how they varied by site. The lack of differences observed was not surprising given the three year duration

Figure 6. Soil P concentrations measured from sampling grid at the Raphine site in 2012 and 2015.

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of the study. With such strong site effects, it may take more than 5 years to begin to see many changes associated with stocking methods.

Table 4. Selected biological soil health indices measured in 2015. SIR – substrate induced respiration, C resp. = carbon respiration (microbial activity), N min = potential net nitrogen mineralization, MicC= microbial soil C, MicN = microbial soil N, POM-C- particulate organic carbon, Total C – total organic carbon, DON = dissolved organic N. Except pH all units are mg kg dry wt. soil.

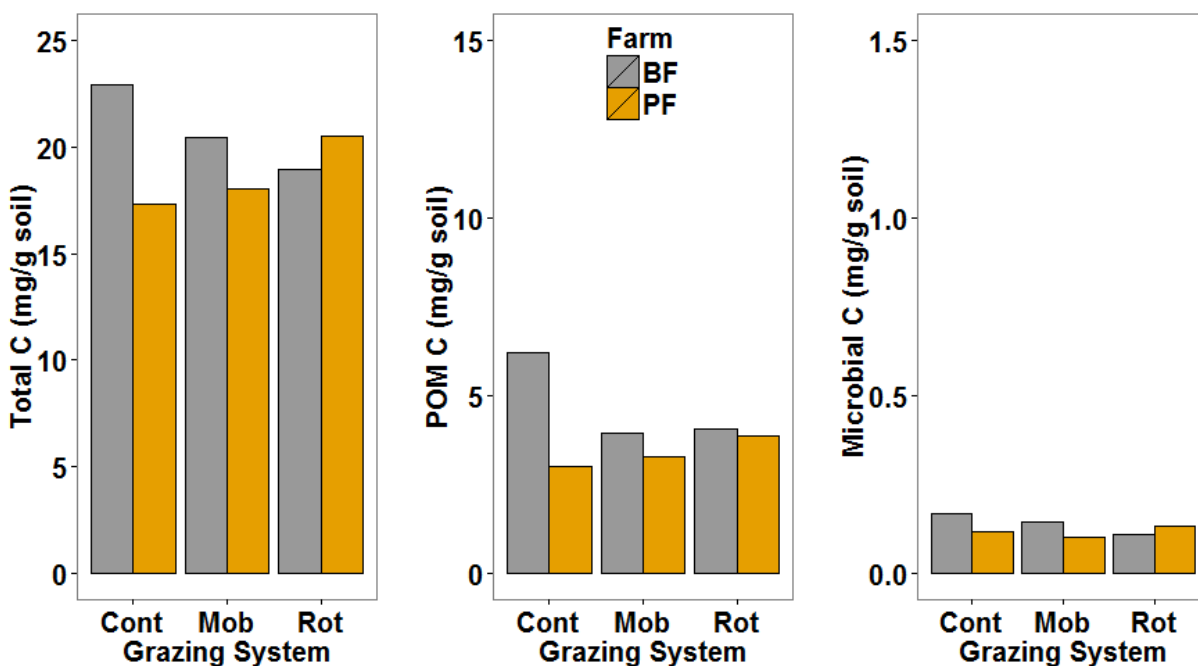|	pH	SIR	C resp.	N min.	Mic C	Mic N	POM-C	Total C	DON
Cont.	6.0	0.71	0.61	15.7	0.14	0.012	4.6	20.1	40.5
Mob	6.1	0.70	0.51	10.9	0.12	0.013	3.6	19.2	34.6
Rot	6.2	0.74	0.58	15.1	0.12	0.011	3.9	19.7	34.9

Figure 7. Three of the soil carbon pools measured in 2015 at the Raphine site (BF) and Blacksburg (PF). Note the variation between sites.

Soil compaction values measured in 2015 were comparatively low under mob stocking **(Figure 8)**. Soil compaction was actually greatest under rotational stocking, but this was mainly a reflection of pre-existing soil conditions at the Raphine location. The rotational paddocks at the site were located on a heavy clay soils series that was unique to that location. Soil compaction indices measured when grazing began in 2013 also show high compaction in the rotational area **(Figure 9).**

Figure 8. Soil compaction measured in 2015. Green line = mob, red line= Cont. and Blue line= rotational.
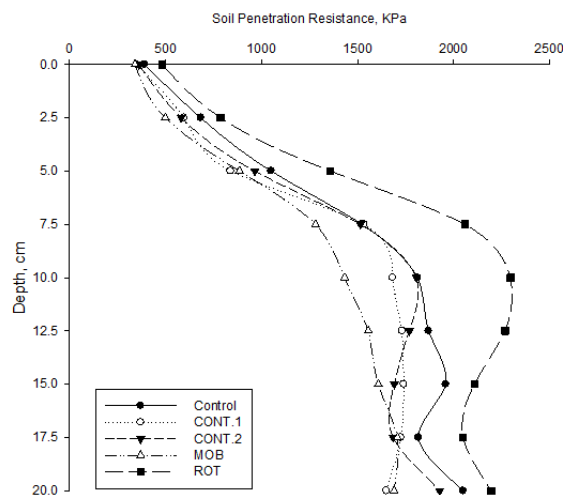

Figure 9. Soil compaction measured in spring 2013 before grazing began at the Raphine site showing heavily compacted soils in the rotational pasture (square symbols).

Soil Nutrient Distribution near Watering Areas

Interesting trends in the data were found for nitrogen mineralization, which is an index of plant available N. We expected high N mineralization rates near watering areas and a gradual decline as distance increases. This trend would be expected when cattle congregate near water areas and deposit manure and urine. This pattern was seen under continuous and rotational stocking but not mob stocking **(Figure 10)**. Under mob stocking, N mineralization was relatively constant across the pasture. In fact, N mineralization rates from 0-10m from waters was almost double under continuous and rotational stocking. Although not shown, data for particulate organic C (POM-C) show a similar trend. POM-C is a carbon pool that represents easily decomposable organic matter and is usually more sensitive to management changes than total carbon. Overall, the patterns might suggest a different cattle behavior with less congregation near water areas under mob stocking and hence less urine and manure deposition there. This result supports the idea the mob stocking with high cattle densities may generate a more even distribution of soil nutrients across pastures rather than the usual high concentration of waste depositions that occur near water or loafing areas.
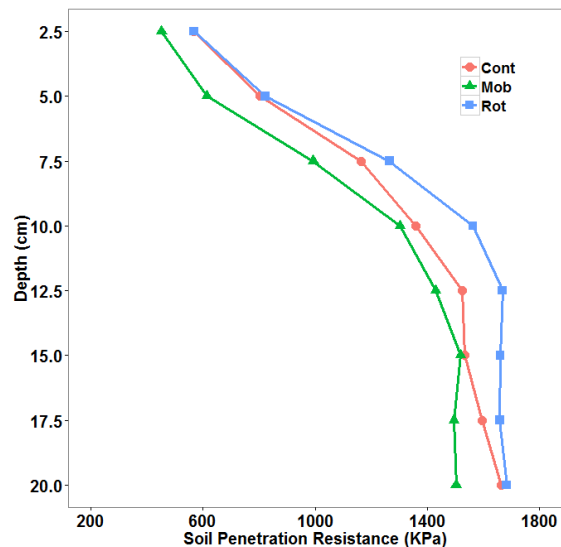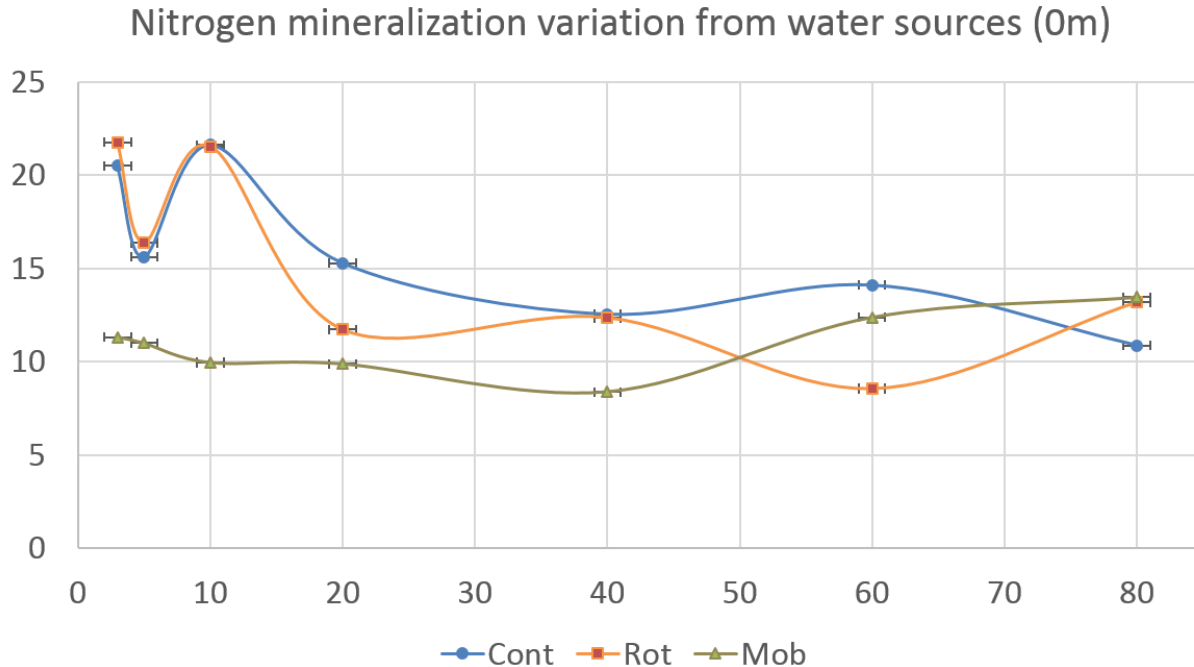
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Figure 10. Net N mineralization measured at 7 locations from water sources. Values on x-axis are meters with the water being at 0m. Mob is the green line with triangles.

Soil Erosion and Runoff

The table below was compiled by Dr. Cully Hession and his former graduate student Emily Williams (Virginia Tech, BSE Department). The data show mean runoff (RO), and total phosphorus (TP) and total nitrogen (TN) collected from rainfall simulations at the Blacksburg site. Both concentrations and load values are given for 5 rainfall simulations conducted in 2013. No distinct trends were apparent when comparing the three stocking methods although TN concentrations were higher during mob stocking rainfall simulation #6, which followed the last mob grazing event. TN loads however were similar for that event. So although runoff had higher N concentration, the actual amount of N in runoff was fairly low due to low runoff from the mob stocked pasture. The amount of runoff and nutrient loss from pastureland is strongly related to vegetation cover. Namely, high runoff amounts and nutrient losses tend to be associated with low vegetation cover/biomass. Vegetation cover likely was not suppressed enough in our study to result in substantial differences among the stocking systems. For example as Table 1 shows, the amount of bare ground cover measured during the growing season never reached above 5%, which means very little soil was susceptible to erosion.

Table 4.6. Response variable means (μ) and standard deviations (σ) from post-treatment conditions (Simulations 2 through 6).

Variable	Treatment	Simulation number 2 μ	σ	3 μ	σ	4 μ	σ	5 μ	σ	6 μ	σ	Post-stocking Simulations μ	σ
RO Volume (mm)	All	11.8	8.9	12.4	6.2	25.3	12.5	29.1	14.4	37.1	12.2	22.8	14.5
	CONT	9.5	8.8	9.1	8.9	31.2	10.7	25.0	12.5	38.0	8.8	22.6	14.7
	ROT	8.4	4.3	12.6	6.4	26.2	16.6	36.7	22.3	43.0	13.2	25.4	18.3
	MOB	17.5	12.1	15.4	2.1	18.7	10.8	25.6	6.8	26.9	14.7	20.4	9.3
Mean TP concentration (mg L^{-1})	All	1.1	0.4	0.8	0.2	0.6	0.1	0.7	0.2	0.6	0.4	0.8	0.4
	CONT	1.4	0.4	0.9	0.2	0.6	0.1	0.7	0.3	0.4	0.3	0.8	0.5
	ROT	0.8	0.2	0.7	0.1	0.5	0.1	0.7	0.2	0.5	0.1	0.6	0.3
	MOB	1.1	0.4	0.8	0.4	0.7	0.2	0.8	0.1	1.1	0.3	0.9	0.3
Mean TN concentration (mg L^{-1})	All	4.39	0.85	4.10	0.67	3.31	0.77	3.52	0.75	4.16	2.02	3.89	1.13
	CONT	5.06	0.95	4.65	0.52	2.75	0.47	2.89	0.44	3.59	0.53	3.79	1.09
	ROT	3.91	0.60	3.68	0.19	3.18	0.39	3.69	0.45	3.18	0.29	3.53	0.46
	MOB	4.18	0.74	3.97	0.84	4.01	0.86	3.97	0.97	6.49	3.63	4.39	1.51
TP load (kg ha^{-1})	All	0.10	0.08	0.08	0.05	0.10	0.06	0.16	0.06	0.17	0.09	0.12	0.07
	CONT	0.09	0.09	0.07	0.07	0.14	0.08	0.13	0.07	0.14	0.13	0.11	0.08
	ROT	0.05	0.04	0.07	0.02	0.08	0.04	0.18	0.08	0.16	0.05	0.11	0.07
	MOB	0.15	0.08	0.10	0.04	0.09	0.05	0.16	0.04	0.22	0.06	0.14	0.06
TN load (kg ha^{-1})	All	0.40	0.26	0.39	0.18	0.61	0.26	0.80	0.37	1.14	0.26	0.66	0.38
	CONT	0.35	0.28	0.30	0.25	0.62	0.16	0.58	0.39	1.12	0.34	0.59	0.39
	ROT	0.27	0.15	0.36	0.17	0.64	0.38	1.01	0.49	1.16	0.35	0.69	0.46
	MOB	0.57	0.32	0.51	0.05	0.58	0.32	0.81	0.12	1.15	0.01	0.69	0.29

Conclusions and Recommendations

- Compared with rotational stocking, mob stocking offered few clear benefits to forage production and soil health. Although mob stocking may produce more forage and result in reasonable forage quality, few soil health indices were improved by this stocking method.

- One advantage of mob stocking may be that it can help prevent cattle from congregating near water sources and depositing manure and urine in those areas. If correct, this may mean that manure and urine derived nutrients may be spread more evenly over the pasture rather than around water areas where they do not aid overall pasture growth.

- Given more intensive management needed for mob stocking (e.g., frequent cattle moves) it is difficult to recommend changing methods if farmers are already using rotational stocking.

- It should be noted that this study was conducted over three years, and more time is needed to see changes in soils in response to grazing management.

- More resources should be allocated to help fund longer-term grazing studies to better document the value of mob and rotational stocking. Resources also should be allocated to farmers interested in adopting more intensive management methods like rotational and mob type stocking so that more on-farm information can be generated and evaluated.

Outcomes in Response to Deliverables for Virginia CIG

1. *Deliverable: Demonstrate how grazing management can affect soil health, pasture plant diversity and nutrient loss in pastures. Assessment will include measurements of: 1) soil health as measured by total organic matter content, particulate organic matter content, soil microbial activity, root mass, physical properties (bulk density and soil compaction), and biological activity (earth worm and dung beetle abundance), 2) soil nutrient distribution across pastures, 3) forage availability, forage quality, ground cover and overall pasture plant diversity, and 4) soil erosion and runoff.*

   Outcomes – this deliverable was largely met as summarized in the Results section. Several variables were not measured, however. Earthworm and dung beetle activity was not accessed in 2015 because a critical time window in the spring was missed when such measurements need to be made ideally. We also did not measure root biomass primarily due to time constraints due to the longer than expected duration of laboratory analyses done for other soil indices. Like the other soil variables we measured, however, it is highly unlikely any of these variables would have differed among the stocking methods due to the short term evaluation period.

2. *Deliverable: Provide science based information to livestock producers, Virginia Cooperative Extension Agents, and NRCS personnel about the benefits of 'mob' and rotational grazing in Virginia.*

   Outcomes - Most deliverables have been met or in the process of completion (see below).

3. *Specific deliverables will include (at minimum):*

   - *3-5 evening pasture 'walks' for livestock producers and other stakeholders to see the demonstration sites and learn about the CIG project*

     ✓ Two pasture walk sessions were conducted at the Raphine site (May 2013) and Shenandoah Valley Agriculture and Research Education Center (May 2014). Informal pasture walks were conducted in September 2013 and 2014 at the Blacksburg site.

   - *A one day grazing management workshop targeting livestock producers in year 2 or 3 highlighting results from demonstration studies*

     ✓ Workshop entitled "Mob Grazing: Practice and Science" was conducted in December 2015 in Blacksburg, Va. - 20 in attendance.

   - *A one day in-service training in year 3 for VCE agents and NRCS personnel focusing on grazing management and highlighting findings from study*

     ✓ In-service training was conducted for NRCS personnel in May 2015 – 40 in attendance.

- *Two scientific publications in journals or meeting proceedings***

  - ✓ Tracy, B.F. and R.B. Bauer. 2015. Mob Grazing Research Update. 2015 SVAREC Field Day proceedings Shenandoah Valley Agricultural Research and Extension Center. Virginia Tech McCormick Farm. August 2015

  - ✓ Bauer R.B. 2015. Mob Stocking Effects on Herbage Nutritive Value, Herbage Accumulation, and Plant Species Composition. Thesis: Master of Science, Department of Crop and Soil Environmental Science, Virginia Tech. 136p.

  - ✓ Williams, E.D. 2014. A Comparison of Runoff Quantity and Quality between Three Cattle Stocking Methods. Thesis: Master of Science, Department of Biological Systems Engineering, Virginia Tech. 137p

    **Due to the recent completion of data analysis from this project preparation of two journal articles are still in progress and will be submitted in 2016.

4.
- Three popular press articles,

  - ✓ Robert Bauer and Benjamin Tracy. 2014. Mob grazing research update. Virginia Forager Vol. 35. Spring 2014. p. 4

  - ✓ Mob Grazing Shows Possible Production, Ecological Benefits by Tanner Ehmke. CSA News August 2015. pp. 4-8 (Article features our CIG project)

- Two Virginia Cooperative Extension publications**

  **Due to the recent completion of data analysis from this project the two VCE publications are still being prepared and will be submitted in 2016.

- Three presentations at regional or national scientific meetings.

  - ✓ Oral Presentation: Benjamin F. Tracy, Robert B. Bauer, Steffany Yamada and Michael Strickland. 2015 Could High Density Rotational Stocking Promote Higher Productivity, Resiliency and Carbon Sequestration Potential? 2015. Abstract 390-4 2015 ASA-CSSA-SSSA Annual Meetings. Minneapolis, MN

  - ✓ Oral Presentation: Robert Bauer, Benjamin Tracy. 2014. Mob Grazing Effects on Pasture Yield and Nutritive Value in Virginia. 124-9 Abstracts ASA-CSSASSSA Annual Meetings. Long Beach, CA.

- ✓ Oral presentation: Benjamin Tracy. Grazing Management for Soil Health. NRCS Invited Talk 3rd Annual Virginia NRCS Conservation Innovation Grant (CIG) Showcase. January 2015. Petersburg, Va. 50 attendees.

- ✓ Oral presentation: Tracy B. June 2014. "Update on Mob Grazing Studies" Livestock-Dairy-Forages In-service. Blacksburg, Va. 40 attendees.